Ground controlled interception & Integrated air defense systems

Even before the first SAM systems for air defense were developed such equipment and methods which aided the successful interception of attackers for defending fighters.

From very early detection and command systems were developed the conception of integrated air defense systems (IADS) which became capable to command SAM batteries or fighters in semi-automatized or automatized way but the path was long and rough to the goal. Eventually later the SAMs and interceptor fighters were commanded by the same systems which carried out target sorting and assignment. The very first of ground controlled interception systems were developed in the 1930s but these systems were far from any later IADS for example they totally lacked any automatization and they did not have even radar.

Before radars acoustic location devices (on left) were used[1] to locate incoming targets. The bearing of targets could be measured with some degree accuracy comparing to the position of the locator in case smaller aircraft groups. Bearing tracking was possible but determining target distance and flight altitude was impossible. (In case of interference of different source and echo in case of lots of targets the method had limitations.)

The speed of data transfer was limited by the radio speech which meant strong limitation; triangulation method was literally impossible because of data transfer delay. By knowing the position of acoustic locators and a bearing fighter pilots at least could get a direction where the targets shall be visually none of fighters had radar before World War II. This was far from perfect because of the communication delay and limits of the human eye but was better than nothing.

The first ground controlled interception (GCI) system was developed in Great Britain just before World War II and very soon saw real combat in 1940 during the Battle of Britain. The resolution and sensitivity of radars made possible to detect and track smaller aircraft groups from much bigger distance than using acoustic locators with better resolution. Comparing to acoustic locators radars are able to measure better the bearing moreover are able to provide target distance and in some cases target altitude either (or at least altitude estimation was possible).

Considering tactics and capability of fighters in early '40s it was a huge step forward it made possible to alert fighters units in time moreover, coordination of fighter squadrons was possible depending on the current tactical situation with radio.

Because of limited flight time and range of fighters combat air patrols (CAP) were not used as today,[2] CAP could be done only in very limited way. Practically only fighters of carrier vessels carried out such patrols

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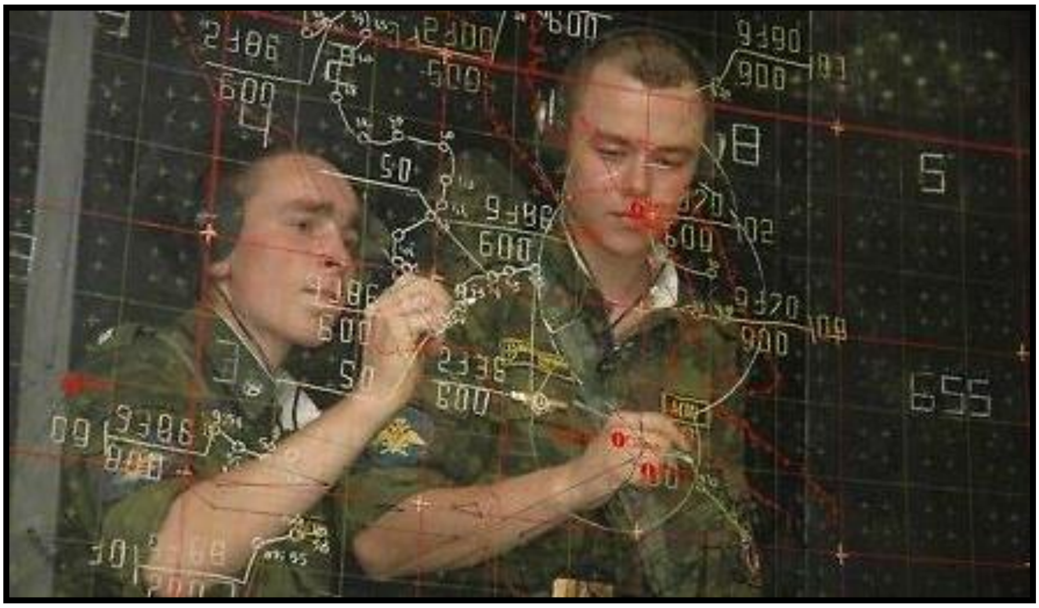
[1] https://goo.gl/31Qmwl, http://www.douglas-self.com/MUSEUM/COMMS/ear/ear.htm

[2] *Practically was close to impossible. With long range bomber escort fighters of late stage of the war (P-38, P-51) in theory could be done but simply was no need of the Allied side maybe only against V-1 Flying bombs. The incoming vector of the V-1s was static in case of land based launch ant-aircraft guns were more suitable then using fighters. During the Operation Cerberus in 1942 Germans fighters provided CAP above the Channel similar to CAP of carriers but only with fraction of the total available aircraft quantity. Most of allocated fighters were only in high alert in case of need increasing for a short time the available fighter power.* https://en.wikipedia.org/wiki/Channel_Dash ; https://bit.ly/2qtp5Yn

because the location of the target – their home base the carrier – was known, are defense could not be performed by CAP.

The method what was used during World War II was the plot table.[3] The target data (bearing, distance and elevation estimated size of the flight) were forwarded from radar stations to a central command post via radio speech. The tactical situation was updated on the plot table which helped coordinate the defense fighter squadrons they could be alerted and scrambled in time moreover fighters could be guided to intercept point within visual range of targets. The plot table could be a large table with tokens moved by the crew or a large glass surface where contact and target symbols are displayed with crayons.

Plot tables and crew during Battle of Britain in 1940.



Above is another form of the plot table method. According to gathered data of radars the data of contacts are updated with crayons. The update interval rate can be judged by the density of small target contact circles. The data (speed, altitude, heading, etc.9 are also can be displayed. The plot table method is strongly limited by the human factor more than some flights/targets cannot be tracked with this method real time data transfer for decision is not possible even the tactical situational display has considerable delay.

[3] http://www.battleofbritain1940.net/document-12.html, https://www.youtube.com/watch?v=oaASXVW3G5o https://en.wikipedia.org/wiki/Chain_Home

The main limitation of the plot table method is the refresh rate (update time) because of communication delay which makes unusable in case too many targets especially targets are fast. The plot table could lag so much behind the reality which leaded outdated tactical information which made impossible intercept targets for fighter squadrons.

The method was usable only to guide squadron size fighter units against similar size target groups. The point of the system provide best intercept vectors for pilots and good tactical situation to planners for better resource management to carry out the good defensive action with the necessary combat potential as quantity of targets demands. Until squadrons do not return to home and became available against the own forces were not visible and controllable. This method is called ground controlled intercept (GCI).

Following the World War II the GCI still used only ground based radars but thanks to the first computers was possible to build in some automatization into system. The first data link system was introduced in the late '50s which made possible to distribute target coordinates and data for interception not only by speech. The Sweden Draken fighter and between the GCI system STRIL 50/60 provided digital data link in the late '50s much earlier than even any of two Superpowers (USA and USSR) had such technology.

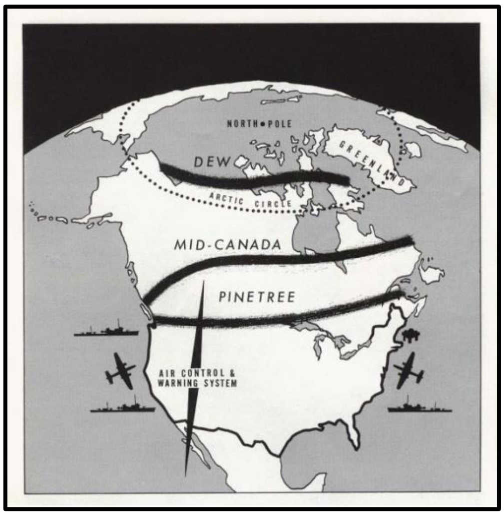
We can say a strongly further developed version and far descendant of early plot table GCI method was the SAGE[4] (Semi-Automatic Ground Environment) system in the USA. It was designed the command the Nike Ajax, Nike Hercules and BOMARC SAMs along with F-102 and F-106 interceptor fighters of late '50s. The SAGE was a very advanced system when reached IOC state in 1958. The gathered data of EW radar barriers (DEW, Mid-Canada Pinetree)[5] could be displayed on a joint screen to make easier the decision and target assignment. The necessary computing capability was supported by the IBM AN/FSQ-7 computer.

The SAGE building at McGuire Air Force Base, circa 1958. On the far left are cooling towers for the generators located in the (low) middle building. The "cube" has four floors, with air conditioning and wiring on the ground, the computers on the second floor, offices on the third and the combat center on top.

The SAGE used the gathered data of the three different radar barriers, Pinetree line entered service in 1955, the DEW in 1957 then the Mid-Canada line in 1958 with low level Doppler search radar.

[4] https://www.youtube.com/watch?v=06drBN8nlWg
https://www.youtube.com/watch?v=euL4y49mGqw
https://www.youtube.com/watch?v=dF75jHfawtM
https://en.wikipedia.org/wiki/Semi-Automatic_Ground_Environment
http://fortwiki.com/Gunter_SAGE_Direction_Center_DC-09

[5] https://en.wikipedia.org/wiki/Distant_Early_Warning_Line



Above are the locations of radar barriers (left) and sites of the DEW line (right).

Pont Lay radar station in Alaska a part of DEW line

Similar systems to SAGE were developed in the Soviet Union both for SAMs and fighters such system were for example the Vektor and Senezh for homeland air defense. Because of the size the first IADS were totally static for army air defense later were developed IADS equipment but army air defense and PVO units could not be in the same network. (See later.)

In 1945 the speed of intercontinental bombers was about 400 km/h or less, in mid ‘50s close to 1000 km/h and M2.0 capable bombers were in development. The limits of plot table method became more and more serious. The point of electronic automatized IADS was reducing the time from contact to display and reducing the decision making to be able to react in time of faster and faster moving targets. The development of IADS started in USSR in ‘50s the first was the ASURK it was designed to coordinate the work Dal (never entered in service) and S-75 Desna batteries around Leningrad. The Russian philosophy classified IADS system into three main categories:

1. Manual, basically is the plot table method with radio, delay is large in minutes scale.

2. “U” type systems, first IADS. Instead of manual plot table and radio the targets are displayed automatically on the electronic plot table the display and update interval is not limited by the human operators and radio speech. The target display for decision making is close to real time

3. “M” type system, standardized IDAS elements from the lowest level (early warning radar units, SAM batteries and higher level command posts), data transfer is digital end encrypted. Not only the display is automatic but decision making is supported with automatizations at least

recommendations are offered for operators. Some IDAS in the Soviet Union from late '80s were capable to guide both fighters and SAMs and could link homeland air defense (PVO) units with army air defense units.

(Regardless for homeland air defense were developed automatized command systems the plot table method survived for very long at least as a backup capability no matter how limited its capability considering quantity of target, delay and refresh rate.)

In first step "U" type systems were developed because manual plot table method is not able deal with lots fast moving targets. Target sorting and commanding SAM units still were manual but the tactical situation which was displayed was close to real time the delay for SAMs (or pilots) was only the decision making and communication time via radio speech. With "U" type IADS was much easier to avoid the situation where some targets are engaged with lots of SAMs or fighters but some of them by none.

The next level of IDAS was when the system offered recommendations by the target parameters and did the target sorting automatically or semi-automatized way considering the readiness state and available missile quantity of SAM sites and remaining fuel and weapons of fighter aircrafts. The IDAS also made possible the triangulation of jamming aircrafts and reducing the usage of fire control radars which lowered the reaction time of engaged aircraft. Using only target acquisition / EW radars of the SAM batteries or other radar units the triangulation was possible with 10 second intervals. Missile could be launched without using the guidance station (fire control radar) of S-75M Volkhov only before 25 seconds of impact had to be turned on the fire control radar.

This meant S-75M batteries in certain IADS became almost immune to AGM-45 because the SAM was launched long before than the AGM-45 which was equipped nose section against fire control radar could be launched. When the (shorter range) AGM-45 became usable and launched the fire control radar of Volkhov could be turned off. Of course this is a very simplified example case in long range engagement but illustrates the benefits of IADS.

Besides the listed factors and issues it has to be noted IADS have many levels and layers in WPACT and USSR on different level different systems were used:

- (SAM) regiment / brigade level IADS, for example the ASURK or Senezh
- (SAM) corps level IADS, for example the VS-11 Vozduh
- Theater level IDAS, for example the Almaz system

The American SAGE system was huge both in physical dimensions and role. The Russian classification method can be applied only partially but we can say it was theater level IADS system. The NORAD Control Center was similar to Alamaz, the DC and CC elements of SAGE were somewhere between Senezh / Vektor. One sub level element could command 2-5 fighter wings and BOMARC batteries.

The capabilities some of the previously mentioned Soviet IADS are the followings:

S-100V ASURK-1

It was introduced in 1963. The S-100V was capable to command one SAM regiment or brigade up to 8 S-75 SAM batteries with their P-14/35/12 target acquisition and height finding radars.

ASURK-1M

It was introduced in 1966. It was capable to command one SAM regiment or brigade up to 8 S-75/125 SAM batteries. The system was exported with 5N74ME Asurk-1ME designation; the date and quantity of exported systems are below (date-qty.).

Egypt 1971-4 pc	Syria 1972-1, 1973-1 pc	East Germany 1972-1 pc	Vietnam 1982-2 pc
Czechoslovakia 1973-1 pc	Romania 1973-1 pc	Iraq 1974-1 pc	Libya 1975-3 pc

ASURK-1MA

It was introduced in 1966. It was capable to command one SAM regiment or brigade up to 8 S-75/125 SAM batteries and one S-200 site (with 2, 3 or 5 batteries).

Vektor-2

It was introduced in 1972. Vektor-2 was capable to command 14 batteries in any composition from S-75/125/200.

5N35E Vektor-2VE

- It was capable to receive and process data of 40 targets with 10 second update interval.
- Vektor-2VE could command 14 SAM batteries in any combination from S-75 and S-125 with 8 targets/minutes with automatic target sorting and assignment considering the technical parameters and state of batteries (quantity of missile, level of readiness, etc.).
- Commanding 5 fighter flights (MiG-21, MiG-23 and MiG-25).[6]

The Vektor-2VE is installed into towed or self-propelled vans but in Hungary (and mostly in other locations either) was deployed to fix hardened sites as the S-75/S-125 batteries. The system was exported in to the following countries:

Poland 1979-1 pc, 1981-1 pc, 1982-1 pc	East Germany 1979-1 pc	Hungary 1980-1 pc (Érd, "Object 20")	Syria 1982-5 pc
Czechoslovakia 1980-1 pc	Bulgaria 1980-1 pc	Cuba 1983-1 pc	

5S99E Senezh-E

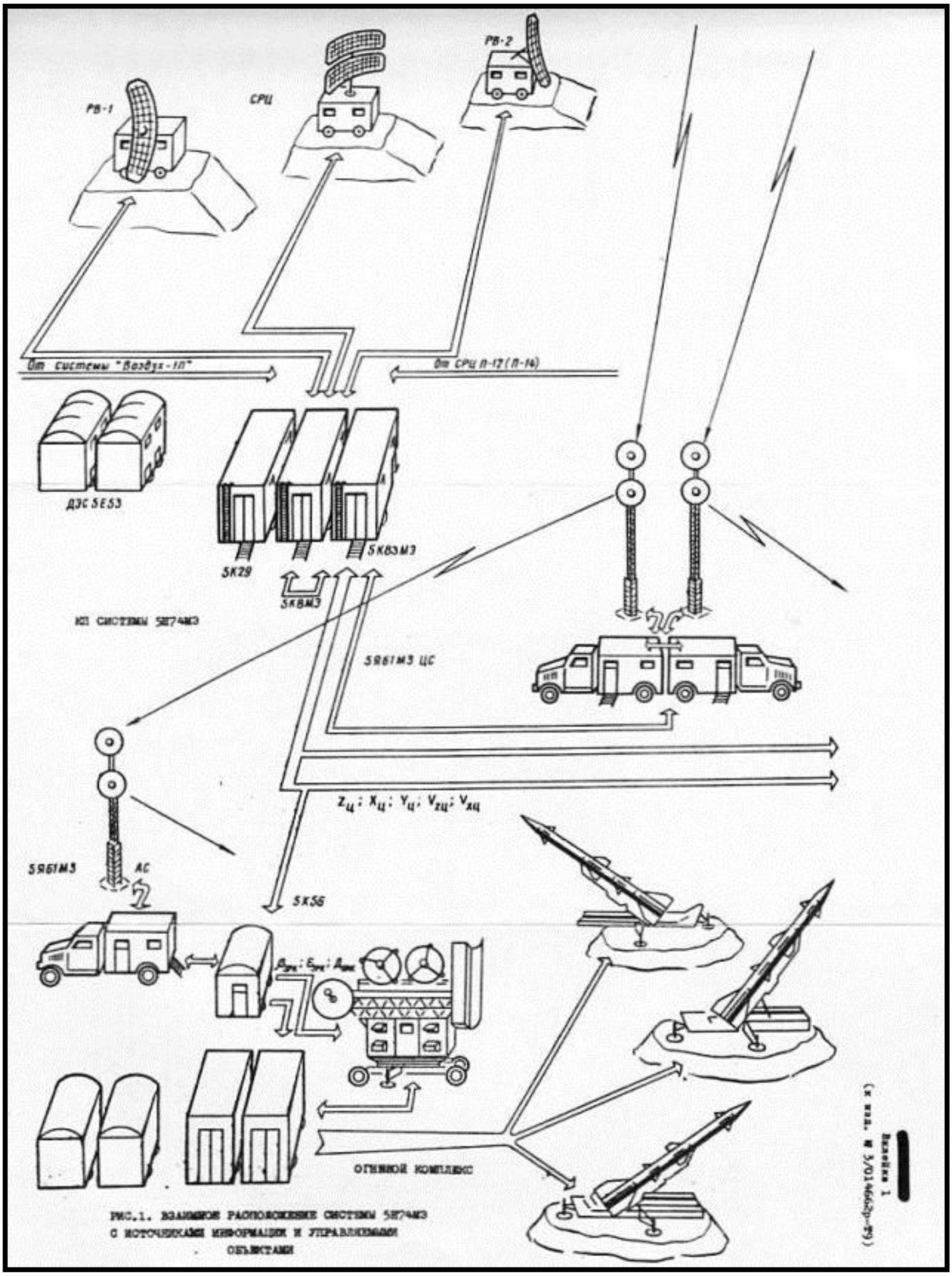
It was capable to track 50 targets (flights) and command 17 SAM batteries (S-75, S-125, S-200, S-300 in any combination) and also was able command 6 fighter flights besides SAM moreover it was capable to triangulate jamming targets by using data of target acquisition / EW radars. The system was installed into vans/cabins but typically was deployed in hardened sites as S-75/125 batteries. It was exported into following countries:

Czechoslovakia 1984-1 pc	Libya 1985-2 pc	East Germany 1984-1 pc

5Sz99ME Szenezh-ME was exported into following countries:

[6] *The flight leader of the interceptor flight can get the target information and forwards via radio. In combat mostly flights engages flights the target assignment within the flights is done by flight leaders therefore the IDAS can command more pilots than flights as long the chain of command works well.*

Hungary 1987-1 pc (Szarvaspuszta, "Object 50")	East Germany 1987-1 pc	
Czechoslovakia 1989-1 pc	Syria 1988-2 pc	Libya 1990-1 pc



Above is the logical scheme of the ASURK IADS. [7]***It was designed to coordinate the target sorting and assignment by the data target acquisition /EW radars and forward the assigned target for the SAM batteries.***

[7] http://simhq.com/forum/ubbthreads.php/topics/3938312/1

VS-11M Vozduh

It was capable to track 60 targets (flights), it could command and coordinate the work of 3 fighter regiments (VP-04M, Rubezh-PORI), 5 SAM brigades (ASURK, Vektor, Senezh), 6 fighter guidance stations (VP-11, Vektor, Senezh) and 1 electronic jamming battalion (AKUP-22) in automatized or semi automatized way.

The listed elements in brackets are the lower level IADS items; the higher level IADS gathered and processed the data then sent back the guidance commands, target coordinates. The VS-11 was able to handle the whole Hungarian homeland air defense it was corps level IADS. In Hungary was installed in Veszprém. (“Object 10” knows as “The Rock.” The system was built in the mountain.)

Above is “The Rock”. The two big round shaped screens are the main display of the system, the big glass table is just the backup for the gold old plot table method.

5D72 Almaz-2

It was capable to connect 7 high level IADS with the neighbor countries. It was exported only to WPACT countries (was not any country where it would have any function). In Hungary was installed in 1985 in Nagytarcsa (“Object 30”) It was capable to forward the whole tactical air picture to Kiev for the Almaz IADS where was possible to merge all the data from IADS of WPACT.

Hungary 1985 (Nagytarcsa,”Object 30”	East Germany 1979	Poland 198?
Czechoslovakia 1980	Romania 1980	Bulgaria 1978

In short these different levels of IADS made possible that on higher commanding level using a merged tactical situation display make the right decisions for SAMs and fighters. The SAMs and fighters can be used much better in coordinated way rather the fighting alone know knowing which targets have already been assigned or engaged to anybody else. One of the main goals was the coordination; another goal was the shorter reaction time which was supported by the automatized or semi-automatized systems and displays on screens and instruments of SAM and fighters.

Through some technical parameters of Vozduh is illustrated who limited was the capability of early IADS considering the computing and data transfer speed of even '90s or today's standard.

The VP-01M was the basic item in the Vozduh which was connected to radars it was designed to display radar contacts from more than one radar and transfer to high level IADS element (VP-02, VP-03, VP-11, etc.)

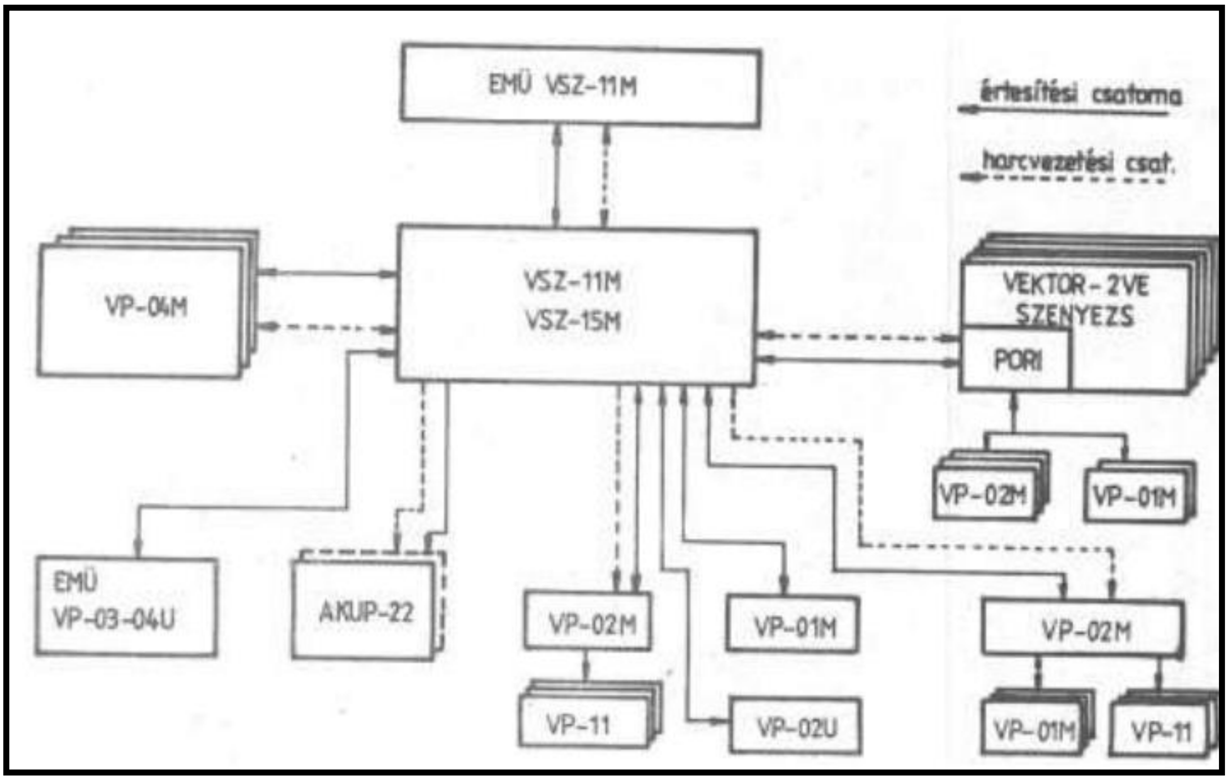
For the VP-01M 2 target acquisition and 1 height finder radar could be connected directly that gathered data of radars were transferred in 32bit encrypted form.

1-8	*bit*	*X coordinate*
9-18	*bit*	*Y coordinate*
19-21	*bit*	*ID/IFF data (country)*
22-28	*bit*	*altitude*

Transfer time of the 32 bit data package was about 0.5 seconds which means 60 Bd (Baud) speed with telegraphic transfer (telex) method. The Vektor IADS has 1200 Bd bandwidth even the most advanced IADS is that time had about 2000 Bd transfer seed which is about 6 kbit/sec. In the mid '90s at dawn of Internet era the modems had 56 kbit/sec bandwidth while the equipment of VP-01M were installed on two URAL-375 truck.

The SAGE had similar main parameters[8] and in its era was considered almost a state of art system. In each directional centers 60 000 vacuum tubes, 175 000 diodes and 13 000 transistors (which was a new thing) were with 256 kB magnetic memory. These made possible the display the gathered data of contacts on 150 CRT screens. The weight of the system was 250 tons (!) with 75 000 operations/seconds.

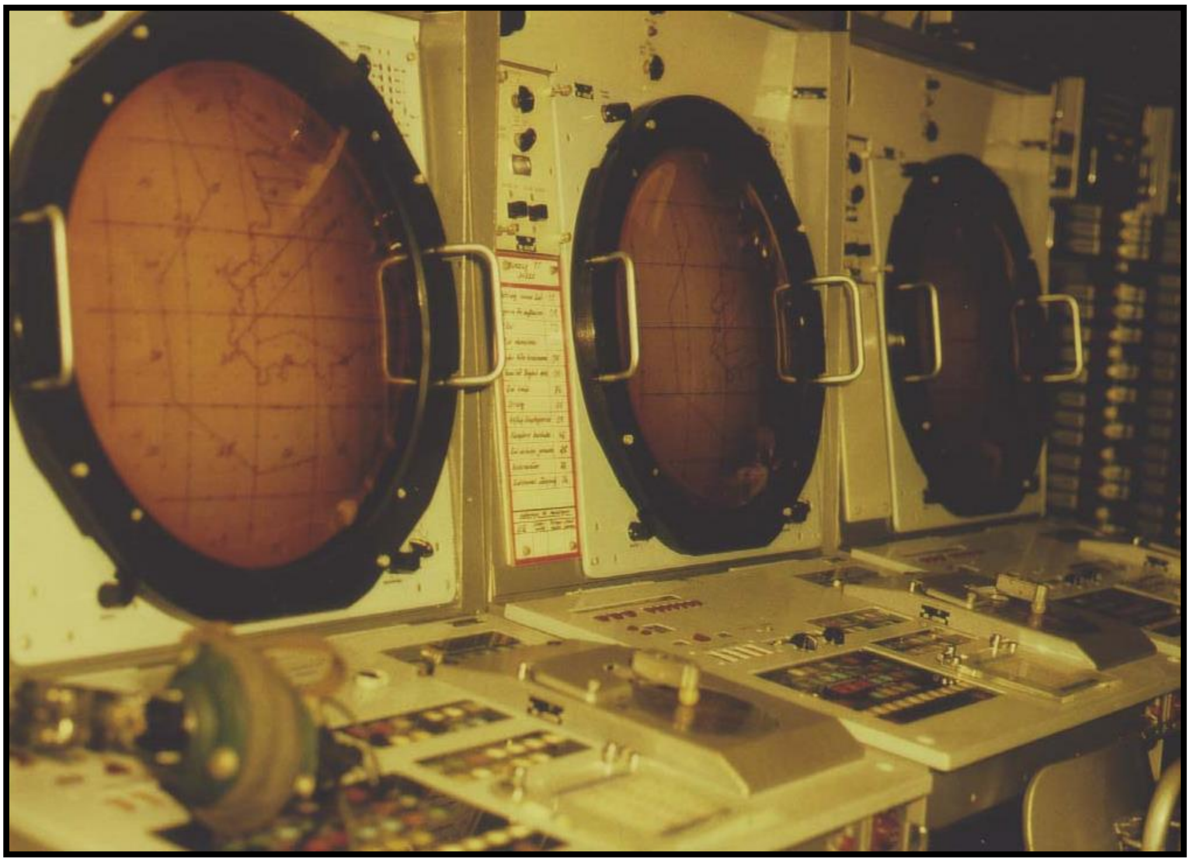
[8] https://goo.gl/9e5kVr
http://ed-thelen.org/sage.html



Logical scheme of Vozduh-M IADS (solid line = notification channel, dashed line = commanding channel)

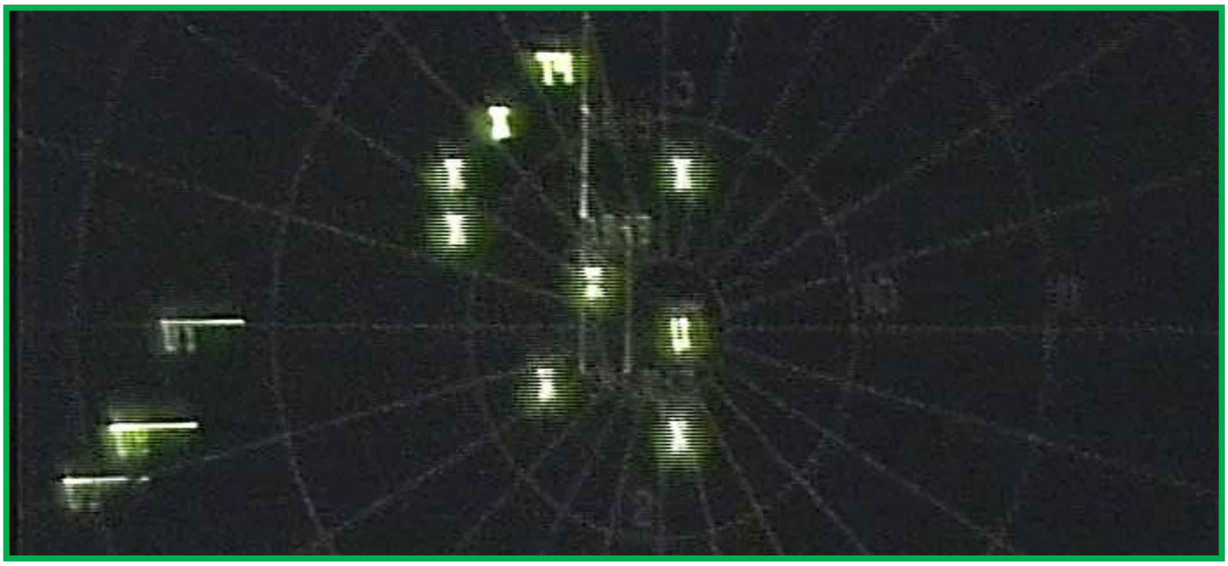
Workstations of the Almaz IADS, above left and right are the "displays" where could be projected the tactical situation.

The ALMAZ IADS during operation, the displayed region (Scandinavia and polar region) gives a good impression about how large airspace could handle the system.



Above are the workstations of PORI IADS. The more screens made possible to provide image for more than one operation about the same space to reach reasonable workload according the quantity of targets.

Workstations of the Vektor IDAS



Screen of a Vektor IDAS terminal symbols are the followings:
X - Sz-75/125 battery, II - S-300PMU battery, 01..03 – targets, 74 – jamming target

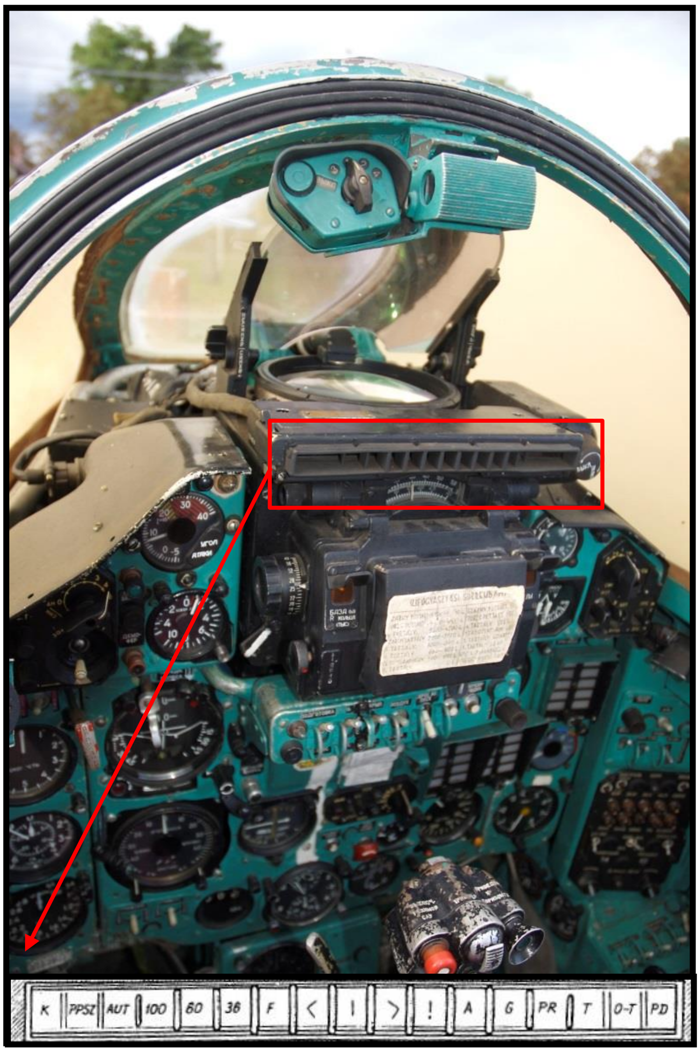
SAGE Subsector Command Post on the 3rd level of DC. It has very similar looking to Soviet Almaz IADS

So far above only the ground stations and terminal of homeland IADS were shown but is worth to say some words about fighters in the IADS through and exact example even the system is very old and was outdated even in ‘80s. For interceptor fighters were designed the Soviet Lazur system which was built in some variants of MiG-21 and MiG-23 fighters.

The Lazur had ground station which was part of the mentioned IADS above. The ground station could send encrypted instructions to the pilots which were displayed on instruments. The instructions were heading, speed and altitude which had to follow the pilot and also got the command when the onboard radar of the fighter could be turned on to perform the terminal phase of interception. Until that point the fighters could remain silent no radio communication or radar emission were required to approach the target.

The instructions were given not in speech; on the ground stations operators used special “electronic typewriters” to give the system the inputs. On the board of fighters the LAZUR instrumentation panel small lighting arrows displayed when had to be climb or descend and turn left or right. A “beep” sound is heard in the earphone every time the LAZUR provided new instructions to the pilot; the pilots did not participated in decision making just followed orders.

On more advanced versions of the MiGs LAZUR and autopilot could be perform maneuvers and follow the instructions of the LAZUR. After takeoff pilot raise gears and flaps, turned on the LAUZUR and only the thrust had to be handled until the command turn on the radar and perform the terminal phase of the interception.



The display panel of the LAZUR system on a MiG-23MF the small lamps are in horizontal row[9]

Main (not all) indications of the LAZUR indicator panels are the followings:

- 100, 60 and 36 indicates target distance during the GCI
- PPSZ, indicates head-on engagement
- F, turn on the afterburner
- <,> and I symbols show the left/right turn or straight flying instructions
- G, engagement with R-23 missile at lower altitude than target
- PR, missile launch is authorized
- T, instruction is returning to base
- OT, brake-off / disengagement
- PD, distance measuring channel of radar is jammed

All the mentioned IADS above were designed to homeland air defense (Soviet/Russian army air defense IADS are in another chapter). Close to the frontline the tactical situation is much more dynamic where is not a good idea to restrict as strongly the pilots as for example the LAZUR does. Of course if anybody which to give better decision making capability for pilots a much better tactical situation shall be provided for pilots. Of course this also means higher workload for pilots.

The two main approach is partially is cultural based – Soviets liked better centralized command approach- but it does not mean USA never used this method. Both MiG-25 and F-106 could be partially remotely controlled (only some systems) it depends on the tactical situation which is better.

One of the main restriction factors for IADS was initially the radar horizon even the best IADS could not help against low level fast targets because of the delay of the plot table methods. The solution was obvious but was harder to make the radars had to placed has high as possible with the guidance operators.[10]

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[9] https://commons.wikimedia.org/wiki/File:MiG-23MF_cockpit_1.jpg

[10] *Installing workstations on AWACS aircraft are not so evident. On the first Sweden AWACS (or sometimes they are called A&EW) were not any operators the onboard system simply transferred the digital target coordinates (and not raw data) to ground based IADS. This means the airborne long range search radar is considered only a specially "deployed" radar in the IADS system, is just another source from many the ground component of the system is mandatory. The E-3 Sentry AWACS also can share and receive digital target coordinates but are operators and*

Considering the size and weights the SAGE and early Soviet IDAS we can get a good impression about the limits of early airborne early warning aircraft. Initially operators saw raw radar screens was possible to give instruction to pilots via radio speech.

Of course the computers and digital technology also brought changes for AWACS aircraft they became capable to part of IADS, for ex E-2 of US Navy could share their data with CIC (Combat Information Center) of the carrier from mid ‘70s and establish digital data link with F-14 Tomcats and E-3 Sentry can send text or target coordination for fighters or send / receive coordinates to Patriot SAM batteries and of course A-50 Mainstay was designed to be part of homeland and also army IADS (see in army air defense chapter.)

workstations onboard which means the E-3 Sentry can operate independently from any ground based IADS, the airplane itself is higher level IADS item can act as a command center.